EXPERIENCE WITH LONGITUDINAL AND TRANSVERSE INSTABILITY DAMPERS IN TEVATRON

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Abstract

We present a short summary of use of longitudinal and transverse dampers in the Tevatron Run II operation (2001-2006).

LONGITUDINAL DAMPER

In the Tevatron Run II, bunch-by-bunch longitudinal dampers were built to suppress the phenomenon of "dancing bunches", longitudinal single bunch and coupled bunch instabilities in the proton beam. The "dancing bunches" are large (~1 rad) RF beam phase oscillations observed in high intensity beams - see Fig.1- that can persist for many minutes in the Tevatron beam after injection at 150 GeV [1].

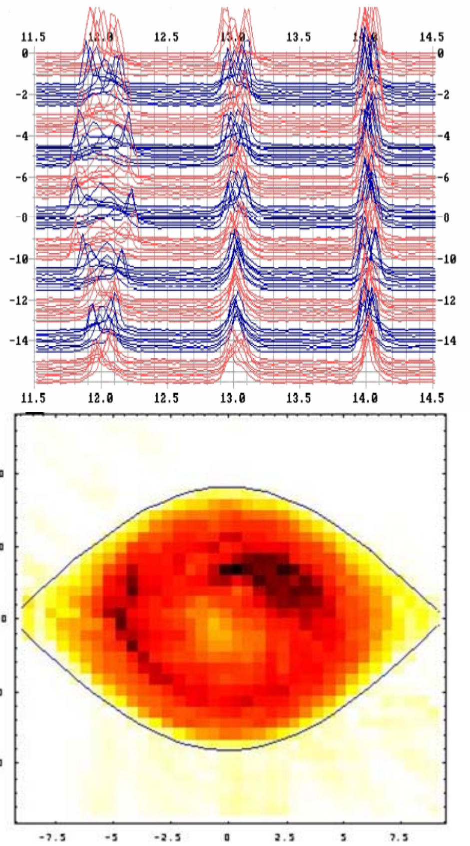


Figure 1: (a) "Dancing" uncoalesced bunches of 150 GeV protons; (b) tomography of the Tevatron bunch [1].

The biggest concern for operations is that the "dancing bunches" result in slow bunched beam intensity loss and increase of uncaptured "DC beam" which is lost at the start of acceleration. Another manifestation of the longitudinal impedances is regular occurrence of large beam RF phase oscillations – see Fig.2. Such blowups are accompanied by significant emittance increase, reduction of luminosity, beam losses and accumulation of particles in the abort gaps - all that is very dangerous for operations. To counteract that, a longitudinal bunch-by-bunch damper was designed, built, installed and commissioned in the Tevatron in 2002 [3]. Since then, the damper is in operation for every store where it is employed everywhere but on the energy ramp. It effectively suppresses both the dancing bunches (not directly demonstrated) and the single and coupled bunch instabilities – see Fig.3. It was found that to be effective, the damper gain should vary slowly during the store in a fashion which tracks proton bunch intensity and bunch length gain *~N/sigma_s*. Unfortunately, from time to time, the instability still occurs. The cause of these instabilities is not understood. Gain adjustment usually helps to re-establish stability. Estimated growth of the emittance due to noise from the feedback system is less than *dEmm_l/dt* < 0.013 eVs/hr (rms).

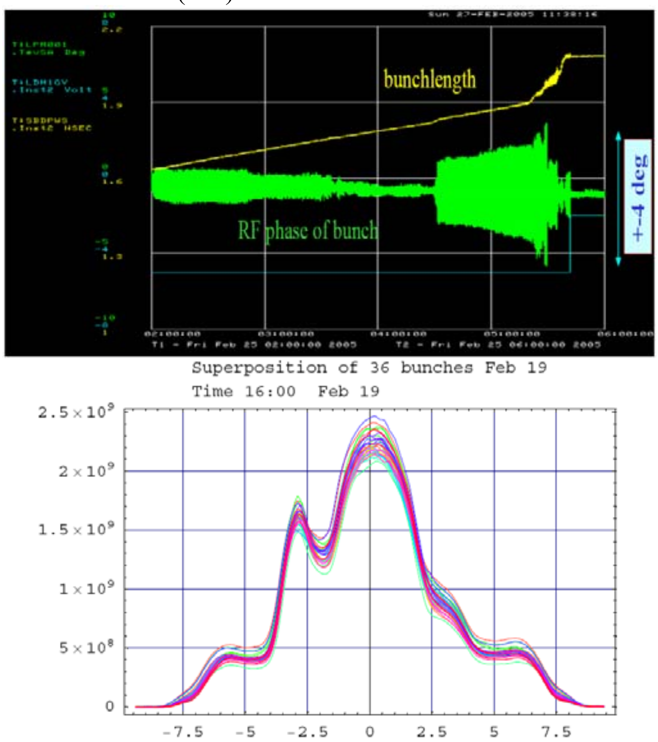


Figure 2: (a) Development of longitudinal bunch instability in the Tevatron at 980 GeV, 1 hr/div; (b) shapes of all 36 proton bunches bunches after the longitudinal instability occurrence [2].

TRANSVERSE DAMPERS

Transverse bunch weak head-tail instability was a serious limitation on the maximum bunch current in the

Tevatron [4]. It manifested itself as a very fast (50-100 turns) development of vertical or horizontal oscillations, and consequent beam loss on the aperture – see Fig. 4 – accompanied by simultaneous emittance blowup of many bunches in the bunch train- see Fig.5. For a long time, the only way to stabilize it was to operate Tevatron with high linear chromaticity in both planes Q'~8-12. High chromaticity values led to very short beam lifetime (see Fig.6) especially in the presence of opposite beam [5]. Interestingly, beam-beam action of antiprotons on protons with very high tuneshift parameter dQ~0.01, did not help stabilization of the proton beam in collisions.

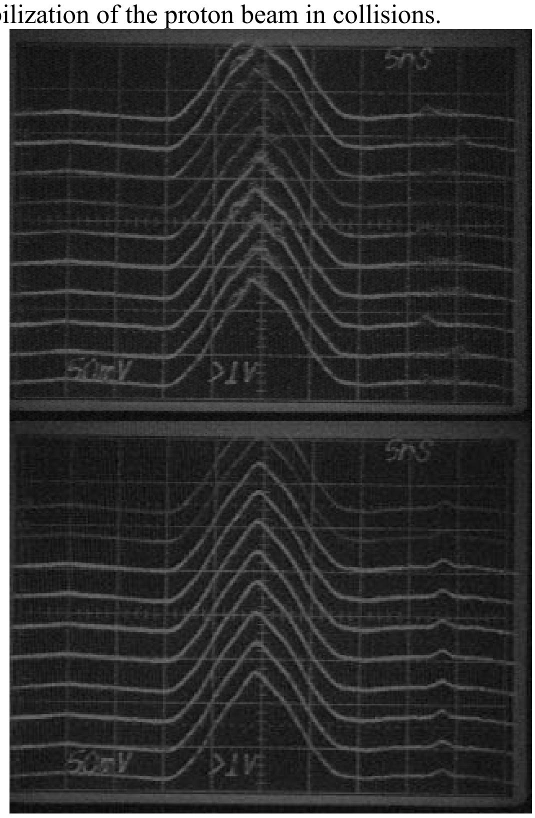


Figure 3: Tevatron resistive wall monitor bunch profiles with (top) longitudinal damper OFF and with the longitudinal dampers ON (bottom). 150 GeV proton bunch, 2.6e11 p/bunch.

It was proposed to install transverse bunch-by-bunch dampers to keep beam stable at lower chromaticity. Such dampers (vertical and horizontal) were built and commissioned in 2002-03[6]. (Tune up of the dampers for each of 36 bunch modes took about 3-4 eight hour shifts).

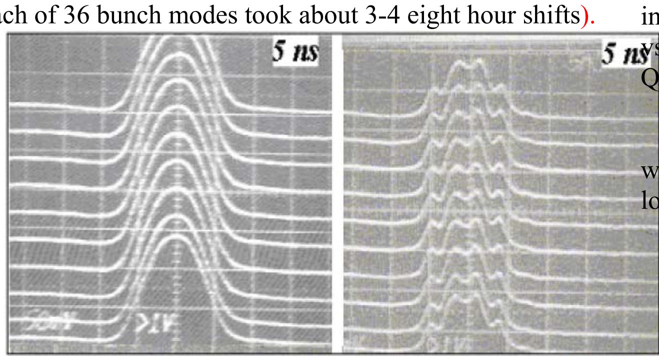


Figure 4:Longitudinal density profiles of (a) the initial (2.6e11) and (b) ramaining (1e11) proton bunches before and after vertical $l=2$ weak head-tail instability[4].

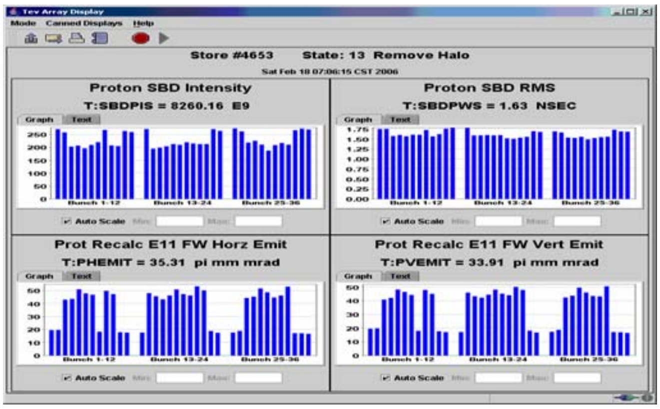
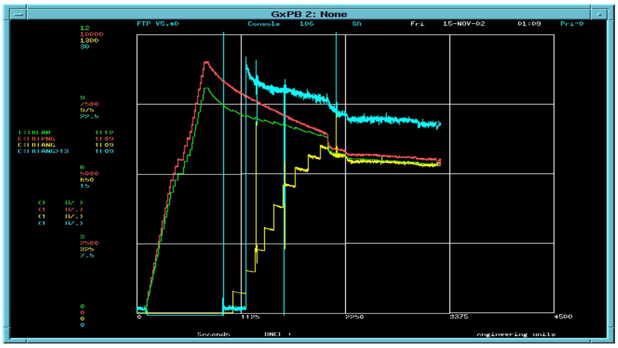


Figure 5: Bunch intensities, rms bunch length, horizontal and vertical emittances of the Tevatron proton bunches Tevatron



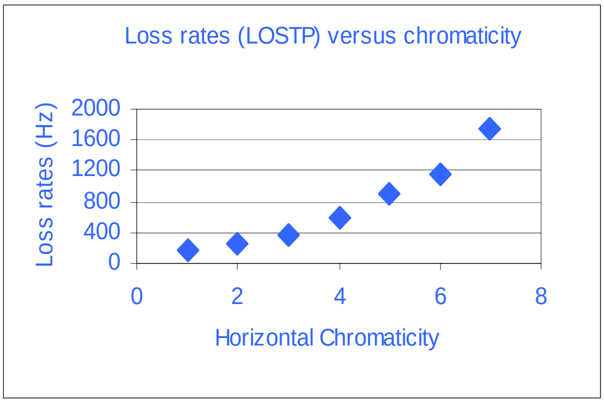


Figure 6: (a) Proton and antiproton intensity decay at injection energy (Nov.15, 2002); (b) loss of protons (a.u.) vs horizontal chromaticity setting (150 GeV, vertical Q'=4, no antiproton beam).

The dampers were in routine operation since then. They were turned ON at 150 GeV, that allowed to run with lower Q' (see table below):

Originally	~2002	Q'~10-16
V/H dampers work	2003	Q'~5-8
Lambertsons lined	2004	Q'~3-5
V fights H damper	Dec'04	Q'~8-10
Octupoles comms'd	Feb'05	Q'~0-3

As seen from above, other methods were later employed for beam stabilization (reduction of Lambertson magnet impedance by installation of a thin conductive liner [4], octupoles) which eventually allowed the reduction of chromaticity to a few (0-3) units at 150 GeV and improved beam lifetime to better than 20 hours. Unfortunately, in December 2004, it was observed that vertical and horizontal dampers "fought" each other – see Fig.7 – so, one of them had to be turned OFF (and correspondingly, Q' in that plane had to be increased) in order to let the other one work. A lot of effort was put into investigation of the phenomena – the leading hypothesis was that it is due to either local or global coupling - but there was no satisfactory resolution. So, as soon as new octupole circuits were operational [7], the dampers were disabled.

On a side note - emittance growth due to the dampers [8] was small, it was not easy to separate it from vacuum and other noises, but one can estimate it to be about dEmm_rms/dt~0.1+-0.1 π μm/hr or <5% of the total at 150 GeV.

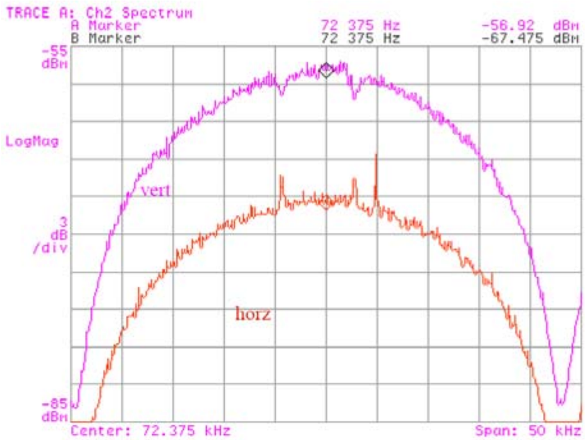


Figure 7: Transverse beam response spectrum. Both dampers are ON. Notice that the vertical damper is suppressing the tune. But the vertical damper is caused excitation in the horizontal plane. Note that horizontal dampers are OFF. (Tevatron Logbook entry Dec11 2002 0811214)

SUMMARY

The installation of longitudinal and transverse dampers were crucial for Tevatron operation. Both types were built to damp individual oscillations of proton bunches. The longitudinal damper is now used at injection energy 150 GeV, turned OFF on the ramp, and turned ON at 980 GeV. It effectively suppresses beam instability. Transverse dampers were in use at 150 GeV only, for almost 3 years (2003-2005), but were eventually decommissioned and replaced by octupoles after we were unable to figure out why vertical and horizontal dampers made each other unstable. Emittance growth produced by noise from the longituduinal and transverse dampers were not of any serious concern for operations or luminosity lifetime.

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